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Research paper

Agricultural residues for energy - A case study on the influence of resource availability, economy and policy on the use of straw for energy in Denmark and Sweden

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ABSTRACT

Denmark and Sweden have an annual cultivation of straw-producing crops on about 16,000 and 11,000 km^2 respectively. However, the actual use of straw for energy differs considerably: 1.35 Tg y^{-1} in Denmark and 0.11 Tg y^{-1} in Sweden. The main objective of this study was to investigate why the use of straw for energy is much larger in Denmark than in Sweden. Differences and commonalities in the conditions for the production and use of straw were reviewed. It was shown that both countries have used a large number of governmental support programmes, as well as monetary instruments (e.g. CO_2-taxes), to promote the use of bioenergy in general. In contrast to Denmark, however, there have been no specific governmental incentives in Sweden directed at increasing the use of straw for energy. One reason may be the vast and relatively low-cost resources of forest biomass in relation to the available resources of straw. The price of competing fuels such as wood chips and wood pellets has generally been 5–15% higher in Denmark than in Sweden. More in depth regional analyses for eastern Denmark and Scania in south Sweden showed that straw production costs are somewhat lower in eastern Denmark as a result of shorter transport distances, earlier ripening of straw-producing crops and better weather conditions during harvest. At present, expert knowledge and the existence of a mature industry favour the large-scale production and use of straw in Denmark.

1. Introduction

Currently close to 60 EJ of biomass is used for energy generation worldwide [1]. More than 60% is used for traditional heating and cooking while the remainder is used in modern conversion technologies for the production of heat, transport fuels, and electricity [1]. Modern use of agricultural residues for energy is so far limited to heat or combined heat and power production at various scales, and to a lesser extent liquid biofuel production.

Various bioenergy projections are set up to meet different goals on energy security and climate change mitigation including targets on agricultural crop residue use. The International Renewable Energy Agency, estimates that 13–30 EJ y^{-1} of agricultural residues must be used by 2030 to meet the Sustainable Energy for all (SE4All) target of doubling the share of renewable energy in the global energy mix before 2030 [2]. Meeting the targets set by the Global Energy Assessment [3] requires extensive use of agricultural residues, with an estimated technical potential of 49 EJ y^{-1} by 2050. More strategically EU member states include agricultural residues in their National Renewable Energy Action Plans (NREAP) to meet the obligations of the Renewable Energy Directive (EU-RED) of 2009.

Bentsen et al. [4] estimated the current global theoretical potential of primary agricultural residues from cereals and sugar cane to approximately 3.7 Pg of dry matter annually, corresponding to 65 EJ y^{-1}. Earlier studies find the theoretical potential of cereals and sugar cane residues to be 2.7–3.5 Pg y^{-1} [5–8], corresponding to 47–61 EJ y^{-1}. Cereals and sugar cane account for 80% of the total residue production [6] and constitute the part easiest to harvest. Technical and sustainable potentials of agricultural residues are logically significantly less. Technical potential can be defined as a fraction of the theoretical potential that can be harvested with current technology under constraints on e.g. topography and accessibility [9]. A certain amount of residues must be left onsite to protect soil productivity. Scarlat et al. [10] summarised research on sustainable removal rates for a number of crops, and report rates between 15 and 60% for most crops. For the EU27 Kluts et al. [11] summarised a range of studies reporting a

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Table 1
Number of energy facilities using straw and their estimated use (Ggt y^{-1}). Information on Sweden is valid for the period 2005–14 and builds on [25–28]. Information on Denmark is valid for 2015 and builds on confidential production census data made available by the Danish Energy Agency, annual energy statistics [30] and Nielsen and Plejdrup [31]. Data are summarised per production facility. Some facilities have more than one production unit, e.g. one district heating boiler and one CHP unit. Data cover all of Sweden and Denmark respectively.

	Small scale local heat production	Medium scale local heat production with excess for sale	Medium scale district heating [a]	Combined heat and power production	Production of vehicle fuels	Total use
Sweden						
No. of facilities	100[b]	40[b]	4	0	0	
Estimated use	50[b]	50[b]	12			112
Denmark						
No. of facilities	6,902[c]		58	27	0	
Estimated use	339[d]	2	390	592		1323

[a] Incl. non-residential and industrial heating.
[b] Uncertain, approximated value.
[c] Based on Nielsen & Plejdrup [31].
[d] Includes residential use and use in the agricultural sector.

sustainable or ecological straw potential of 1.9–3.1 EJ y^{-1} by 2020.

The current use of crop residues is poorly known [4], as very few countries collect data on residue production and use. A number of modelling studies find, on a global level, the current appropriation (incl. for energy) to between 41 and 66% of total residue production [7,12,13]. The IPCC special report on renewable energy [14] reviewed the vast body of literature on bioenergy resources and reports the technical potential of agricultural residues, including processing waste (secondary residues) by 2050 to be 15–70 EJ y^{-1}.

In Denmark and Sweden agricultural residues traditionally used for energy are straw from cereal (wheat and barley) and oil crop (rape seed) production. In Sweden, the total acreage of cereal and oil crops is about 11,000 km^2 [15] and the actual use of straw for energy purposes about 0.1 Tg y^{-1}. In Denmark, the corresponding values are 16,000 km^2 and 1.3 Tg y^{-1}, respectively [16]. The costs for straw varies widely depending on yield, harvest techniques, transport distances, storage facilities, payment to farmers for the straw (incl. compensation for removal of nutrients) etc. Thus, the production costs are strongly dependent on local or regional harvesting and handling conditions.

The main objective of this study is to investigate why the use of straw for energy is much greater in Denmark than in Sweden. Earlier studies on straw to energy have treated specific issues differing between Denmark and Sweden, e.g. the organisational framework [17]. Here we cover not only organisation, but also the political framework, resource competition, logistical and economic issues, climate and agricultural tradition to paint a coherent picture of factors driving the use of straw for energy in Sweden and Denmark.

2. Material and methods

Differences and commonalities in the conditions for the production and use of straw are reviewed. The study assesses the development of policy frameworks as well as market conditions (prices, competing fuels etc.) and production costs. More in depth regional analyses are carried out for eastern Denmark and Scania in south Sweden. These regions, separated only by a narrow strait (Öresund), have several commonalities including landscape type, arable farming conditions and climate, but differ significantly regarding the use of straw for energy. The analysis is based on a review and analysis of data from scientific literature, policy strategies, government documents, and censuses.

3. Results and discussion

3.1. Current use

According to Voytenko and Peck [17], straw fuel users can be divided into four different categories depending on organisational and structural levels. The small scale local heat producers typically produce grain on their farms and have a heat demand in production facilities and for grain drying. They often have batch-fired boilers (normally $<$ 600 kW). The main reason for installing small boilers is economic. Expensive fossil oil is replaced by cheaper straw from the farm. Medium scale local heat producers often have continuously-fed boilers (1–1.5 MW) with straw shredders. Besides self-use, they also sell excess heat to neighbours or to a local district heating network [17]. A third category, medium scale boilers, produces heat for district heating. Larger plants in this category (up to 6 MW) can be owned privately or by the municipality, farmers or consumer/producer cooperatives. The supply of straw is often managed through formal contracts with straw suppliers, who in turn may have sub-contracts or agreements based on mutual trust with farmers. The main reasons for establishing such plants are economic, legislative and/or political, i.e. there may be a municipality policy to phase out the use of fossil fuels [17]. The large scale power or CHP producer category is the most complex. Sophisticated technology is used for receiving and feeding the fuel into the boiler and for the production of process steam or district heating and electricity. The plants are often owned and financed by big utility companies. Several specialist operators are involved in the value chain from recovery of straw in the fields to trading of electricity and heat, and to the final disposal of ash. The use of straw for the production of liquid or gaseous fuels may be a fifth category. Liquid fuel ethanol can be used for internal combustion engine vehicles and gaseous fuels can be used in place of natural gas, either in the grid or at site to run a CHP plant. In recent years upgraded biogas has received attention as a substitute for fossil transportation fuels. Examples are the production of ethanol through bio-refining of lignocellulosic raw materials [18] and the production of gaseous fuel via anaerobic digestion [19] or thermal gasification [20,21]. The number and type of straw energy providers in Sweden and Denmark is presented in Table 1.

There are no commercial utilities producing vehicle fuels on straw in neither Sweden nor Denmark. A demonstration scale straw to ethanol plant has been running in Denmark since 2009 [22] with the capacity to process 4000 kg h^{-1} of cereal straw [22]. There are no CHP plants using straw in Sweden in contrast to Denmark with 9 large-scale centralised CHP plants in operation [23], one under construction [24], and a number of smaller de-centralised CHP plants. There are at least four district heating plants using straw in Sweden (Skurup, Såtenäs, Trelleborg, Löderup), with a total installed output of about 12 MW and a total straw demand of about 12 Gg y^{-1} [25]. The number of medium-scale plants on farms selling excess heat may amount to 40, of which about 25 are located in Scania [25–28]. The number of small-scale plants, which have an installed output of typically 0.5 MW, may be around 100 [27], with an estimated total use of 50 Gg y^{-1} of straw.

According to a survey from 2012, straw was harvested on 40% of the total area planted with cereals (10.200 km^2) in Sweden [29]. Of the straw from this area, about 73% was used for bedding, about 13% for